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HIGH-PERFORMANCE STRUCTURAL FLAKEBOARDS FROM DOUGLAS-FIR AND LO--ETC(U)
1976 T J RAMAKER, W F LEHMANN
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Abstract

Process requirements were investigated toward making a flakeboard using forest residues which could meet performance goals of the U.S. Forest Service "Structural Flakeboard from Forest Residue" program. These goals represent an estimate of minimum design properties for satisfactory performance of flakeboard as floor and roof sheathing. A first group of panels was made which varied in species, flake alinement, density, and resin quantity, and then was evaluated. A second group was made to investigate structural properties with varying flake moisture content, length of disk face flakes, thickness of ring core flakes, and press closing time. The panel type chosen as most warranting more thorough study was of random flakes in three-layer construction, with 0.02- by 2-inch face flakes and a core of 0.05- by 2-inch ring flakes. The panel was bonded with 5 percent phenolic resin and pressed to a density of approximately 40 pounds per cubic foot.

Acknowledgment

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HIGH-PERFORMANCE STRUCTURAL FLAKEBOARDS FROM DOUGLAS-FIR AND LODGEPOLE PINE FOREST RESIDUES

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Introduction

Forest residues are a potential raw material of major magnitude, and thus seriously concern the Forest Service. These residues, which represent an annual accumulation of over 9 *billion cubic feet* (*ft*^{3}) *of wood are* generated by timber harvesting, thinnings, and natural mortality.

The Forest Service has in progress a research and development program entitled "Structural Flakeboard from Forest Residue." It considers forest residues as they affect two national issues: (1) extension of the timber supply, and (2) timber production in a quality environment. Few Forest Service programs do not relate to environmental improvement. However, extension of the timber supply is the primary objective in the development of structural particleboards from forest residues.

To meet the challenge of extending the Nation's timber supply, two principal possibilities exist: (1) Grow more trees; and (2) better utilize existing stands. To investigate structural panel products made from the 9 billion ft^3 *of forest residues* is one way the Forest Service has sought to improve timber utilization.

This study, a part of the total Forest *Service residue program*, expands on previous research [2,3] in such variables as flake size, random versus *alined* flakes, resin content, and density. The study is to determine the process requirements of a structural particleboard with properties that would produce a desirable floor and roof sheathing material. The purpose of this study also has been to help determine which panel construction would be best suited to attaining the Forest Service's flakeboard performance goals.

Work has been undertaken at the Forest Products Laboratory to determine what basic properties a structural particleboard should have to enable it to perform well as a floor and roof sheathing.

The following performance goals have been developed by analyzing the load and *performance criteria* which are associated with sheathing material in house construction. Values are for dry material of 1/2-in. thickness unless otherwise noted.

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Lehmann, W. F. 1974. Properties of Structural Particleboards. For. Prod. J. 24(1):19-26.

[3]Lehmann, W. F. and R. L. Geimer. 1974. Properties of Structural Particleboards from Douglas-fir Forest Residues. For. Prod. J. 24(10):17-25.

Structural Properties:	
Modulus of rupture (near minimum[4])	4,500 lb/in.^{2}
Modulus of elasticity (average)	800,000 lb/in.^{2}
Hardness (maximum load)	500-1,000 lb
Internal bond (average)	
Dry	70 lb/in.^{2}
After D 1037 accelerated aging	35 lb/in.^{2}
Nailing Properties:	
Lateral nail resistance (average)	300 lb
Nailhead pullthrough (average)	250 lb
Nail withdrawal	
Dry	40 lb
After 24-hour soak	25 lb
After D 1037 accelerated aging	20 lb
Dimensional Stability:	
Linear expansion[5]--30 to 90 pct relative humidity (maximum)	0.25 pct
Thickness swelling--30 to 90 pct relative humidity (RH) (maximum)	8 pct

[4]5 pct lower exclusion limit.
[5]For panels up to 9 ft long.

Raw Material

Representative samples of two species, Douglas-fir and lodgepole pine, were selected for the initial investigation. Douglas-fir comprises 35 pct of the total U.S. softwood residue, and lodgepole pine 20 pct.

The residue came from the northwestern United States and consisted of material greater than 4 in. in diameter and 4 to 8 ft long. This residue was composed of a mixture of approximately: (a) 75 pct sound wood from material greater than 6 in. in diameter; (b) 12.5 pct wood containing up to 50 pct by volume of easily visible decay (estimated to contain 20 to 50 pct decay); (c) 6.25 pct sound wood from material less than 6 in. in diameter; and (d) 6.25 pct bark.

Experimental Procedure

Previous research[6] indicated that optimum structural properties could be attained in flakeboard with a face:core:face ratio of 15:70:15 pct by weight of flakes. Therefore, that ratio was used for all flakeboards in this study. The three-layer construction was selected for all panels because it enabled the use of large amounts of low-grade forest residue in the core. Faces were 0.02- by 0.5- by 2-in. disk flakes. The face flakes (30 pct of the weight) were made from higher quality residues to achieve the desired stiffness and strength in the finished panels. The core, generally, was of 0.02- by 2-in. ring flakes of random width although a few panel types contained 0.05- by 2-in. ring flakes in the core.

Two groups of panels were fabricated for this study. The first group of panels was made as a factorial experiment designed to investigate two levels for each of four qualities: Species, flake alinement, density, and resin quantity. Panels were fabricated in all possible combinations to produce 16 different flakeboards. Complete definition of the alternatives follows:

Species (2).--Douglas-fir or lodgepole pine.

Panel types (2).--Random or alined face flakes (all alined panels had random core flake distribution).

Panel density (2).--37 or 43 lb/ft^3. Density based on volume after conditioning at 64 pct RH and ovendry (OD) weight.

Resin content (2).--5 or 7 pct phenol-formaldehyde (PF) resin solids (based on OD weight of wood).

[6]Geimer, R. L., H. M. Montrey, and W. F. Lehmann. 1975. Effects of Layer Characteristics on the Properties of Three-layer Particleboards. For. Prod. J. 25(3):19-29.

Table 1. -- Variables in second group of flakeboard panels[1]

Board code[2]	Face moisture content	Core moisture content	Face flake size (disk flaker)	Core flake size (ring flaker)	Press closing time
	Pct	Pct	In.	In.	
			DOUGLAS - FIR		
10 - 10 - .02 - 3	10	10	0.02 x 1 x 3	0.02 x 2	1 min
10 - 10 - .05 - 2	10	10	.02 x 1 x 2	.05 x 2	1 min
10 - 10 - .05 - 3	10	10	.02 x 1 x 3	.05 x 2	1 min
12 - 8 - .02 - 2	12	8	.02 x 1 x 2	.02 x 2	30 sec
12 - 8 - .02 - 3	12	8	.02 x 1 x 3	.02 x 2	30 sec
12 - 8 - .05 - 2	12	8	.02 x 1 x 2	.05 x 2	30 sec
12 - 8 - .05 - 3	12	8	.02 x 1 x 3	.05 x 2	30 sec
[3]12 - 8 - .05 - 2	12	8	.02 x 1 x 2	.05 x 2	30 sec
			LODGEPOLE PINE		
8 - 8 - .02 - 2	8	8	.02 x .05 x 2	.05 x 1	1 min

[1]All boards made from residue (75 pct sound and greater than 6 - in. diameter; 6.25 pct sound and less than 6 - in. diameter; 12.5 pct with up to 50 pct decay; 6.25 pct bark). The decayed wood, sound wood less than 6 - in. diameter, and bark were used in core only. Boards were made to 40 lb/ft^3, with 5 pct phenol-formaldehyde resin and 1 pct wax, 10 - min. pressing at 350° F. Face:core:face ratio: 15:70:15. Random face and core flakes.

[2]Meaning of the four-number code (left to right): (1) face flake moisture content (pct); (2) core flake moisture content(pct); (3) core flake thickness (in.); (4) face flake length (in.).

[3]Formed mat held 18 h before pressing.

In addition, boards were made at 40 lb/ft^3 density and 5 pct resin content in Douglas-fir, random face flake series. Duplicate panels were prepared at each level for a total of 34 panels in this group.

The second group of 16 Douglas-fir panels was made to investigate the effect on the properties under study of moisture content of face and core flakes, length of disk face flakes, thickness of ring core flakes, and press closing time. This second group also included two lodgepole pine flakeboards to further study effect of moisture content and flake size. All boards of this group were made to a target density of 40 lb/ft^3 and contained 5 pct phenol-formaldehyde resin and 1 pct wax. Specific data for each variable for the second group of panels are shown in table 1.

The following processing steps were followed in preparing the material, pressing, and conditioning the panels for both groups prior to laboratory evaluation.

Panel size: Rough--1/2 by 24 by 28 in.
Trimmed--1/2 by 22 by 26 in.

Face:core:face ratio: 15:70:15 pct based on weight of flakes

Resin binder: Liquid phenol - formaldehyde with 43 pct resin solids

Wax: 1 pct wax solids from wax emulsion (based on OD weight of wood)

Mat moisture content: 10 ± 0.5 pct in first group (based on OD weight of wood, resin, and wax). Varied in second group.

Press temperature: 350° F

Total press time: 10 min (1 min to stops for first group, 30 sec for second group).

Hot-stacking: Panels were placed in an insulated box for at least 12 h following removal from hot press.

Conditioning: Panels were placed in a room maintained at 73° F and 64 pct RH and conditioned to practical equilibrium.

In total, 52 boards were prepared.

Panel Testing

The panels were prepared for evaluation by cutting them into test specimens. Before making the mechanical property evaluations, each specimen was conditioned to equilibrium moisture content (EMC) at 73° F and 64 pct RH. Procedures outlined in ASTM D 1037 were followed as closely as practical in the tests outlined below:

1. Static bending: Modulus of rupture and modulus of elasticity.
2. Internal bond.
3. Nail tests: Lateral nail resistance, nail withdrawal, and nailhead pullthrough.
4. Hardness.
5. Dimensional stability: Water absorption, linear expansion, and thickness swelling.

In the case of the panels with random face flakes, the cutting plan produced four bending specimens. In boards with alined face flakes,

there were two bending specimens with the face flakes parallel and two with the face flakes perpendicular to the specimen long direction. Two replications of each treatment in the factorial design resulted in eight bending specimens of like configuration for the random boards and four for the alined.

Five of the standard tests--static bending, internal bond, direct nail withdrawal, and nailhead pullthrough--were also performed on specimens after they were exposed to the ASTM D 1037 accelerated aging process. In the nail withdrawal test, the nail was driven into the test specimen before accelerated aging. During test, the nail was withdrawn until movement occurred; then the specimen was reversed and the nailhead pullthrough test performed using the same nail.

A slightly modified lateral nail resistance test was used in this study. Nails were driven 1/2 in. from the edge and then loaded to failure using a clamp holding the nail from only one side of the specimen.

The series of dimensional stability tests included measurements of linear expansion (LE), thickness swelling (TS), and water absorption (WA), in exposures at 50 to 90 pct RH, 30 to 90 pct RH, 24-h watersoak (group 1 specimens only), and ovendry-vacuum-pressure-soak (OD-VPS) conditions.

Analysis of Results

Strength and Elastic Properties--Group 1 Panels

Strength and elastic properties were determined for the first group of test specimens, with the unaged and aged static bending properties presented as follows:

Species	Flake alinement	Presented in--
Douglas-fir	random	table 2, figure 1
	alined	table 3, figure 2
Lodgepole pine	random	table 4, figure 3
	alined	table 5, figure 4

In addition, five other properties for unaged and aged group 1 flakeboards--internal bond, direct nail withdrawal, nailhead pullthrough, lateral nail resistance, and hardness--are presented in table 6.

The modulus of elasticity (MOE) and modulus of rupture (MOR) values of the various density Douglas-fir boards in table 2 and figure 1 generally increased as the density increased, while resin content had little effect on properties. The optimum density appeared to be near 40 lb/ft^3.[7] The panels produced at this density resulted in an MOE of 773,000 lb/in.^{2} and an average MOR of 5,100 lb/in.^{2}

Note here that the 4,500 lb/in.^{2} in the Forest Service performance goals is a near-minimum value. Therefore, the MOR of these boards cannot be compared with these performance goals until a large enough sample (approximately 50 specimens) is tested to establish exclusion limits (near-minimum value).

The Douglas-fir alined boards (table 3 and fig. 2) surpassed the performance goals in MOE and near-minimum MOR in the major panel direction (parallel to alinement). Density here had less overall effect on properties than in the random flake series, and resin content again showed little influence. On the average, these panels were 3.5 and 2.5 times stiffer and stronger in the alined (parallel) direction than in the cross-alined (perpendicular) direction.

Using thickness before aging in all calculations, the effect of D 1037 accelerated aging (figs. 1 and 2) was only slight on the MOE and MOR of the Douglas-fir boards regardless of flake orientation. This was in spite of significant reductions in density, and thus should indicate good durability.

Panels made at low density with random flake lodgepole pine material, table 4 and figure 3, had MOE values 16 pct higher and MOR values 30 pct higher than the low-density Douglas-fir panels. There were only slight differences between species at the higher density levels, and again resin content had little effect on these panel properties.

[7]This density is based on ovendry weight. Thus, in actual use, panels would contain some moisture, normally 8-10 pct, which would increase the panel weight proportionately.

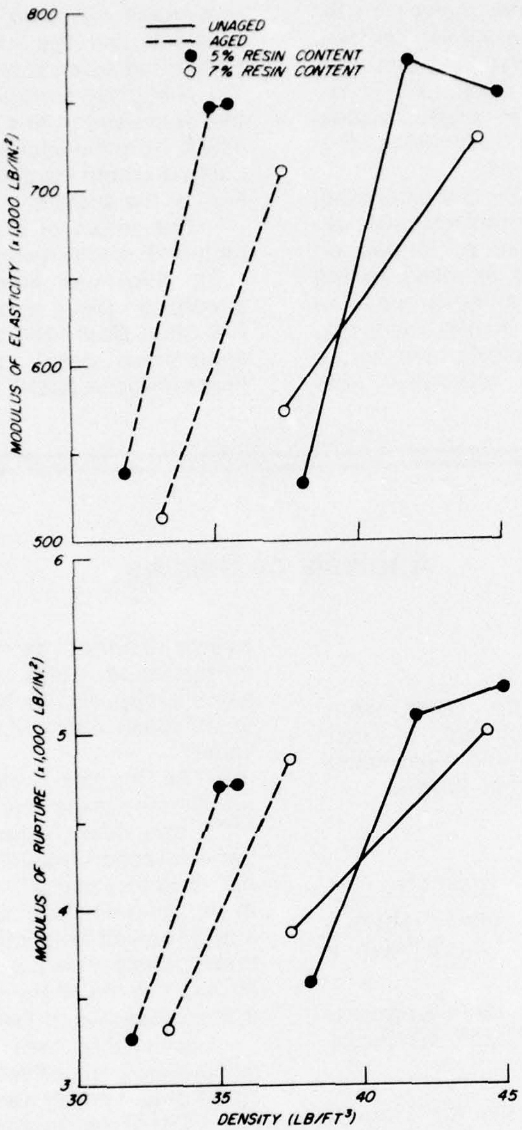

Figure 1. -- Relationship of MOE and MOR to resin content and density for Douglas-fir structural flakeboards with random face flakes, both before and after accelerated aging. (From table 2.)

(M 144 020)

Table 2. — Static bending properties of Douglas-fir structural particleboards with random face flakes

Target density	Resin content	Average moisture content	Density[1]			Modulus of elasticity				Modulus of rupture			
			Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation	Percent of unaged	Average	Standard deviation	Coefficient of variation	Percent of unaged
Lb/ft³	Pct	Pct	Lb/ft³	Lb/ft³	Pct	1,000 lb/in.²	1,000 lb/in.²	Pct		Lb/ft²	Lb/ft²	Pct	
UNAGED[2]													
37	5	8.8	38.1	1.2	3.4	533	28	5.2	--	3,590	436	12.1	--
	7	9.0	37.4	0.6	1.9	574	36	6.4	--	3,870	387	10.0	--
43	5	8.2	44.9	1.9	4.4	754	52	6.9	--	5,260	476	9.0	--
	7	8.4	44.3	1.9	4.0	728	54	7.5	--	5,010	532	10.0	--
40	5	9.0	41.8	1.9	4.9	773	96	12.4	--	5,100	744	14.6	--
AGED[3]													
37	5	9.4	31.8	0.6	2.8	540	52	9.5	101	3,270	307	9.4	91
	7	9.4	33.1	1.2	2.9	513	19	3.7	89	3,320	295	8.9	86
43	5	9.1	35.6	0.6	2.1	748	42	5.6	99	4,720	338	7.2	90
	7	9.0	37.4	1.2	2.6	711	49	6.9	98	4,850	615	12.7	97
40	5	8.8	34.9	0.6	2.4	747	45	6.0	97	4,710	444	9.4	92

[1]Based on dimensions at test and ovendry weight.
[2]Average values based on 8 specimens conditioned to EMC at 73° F and 64 pct RH.
[3]Average values based on 4 specimens conditioned to EMC at 73° F and 64 pct RH. Bending properties calculated using dimensions before aging.

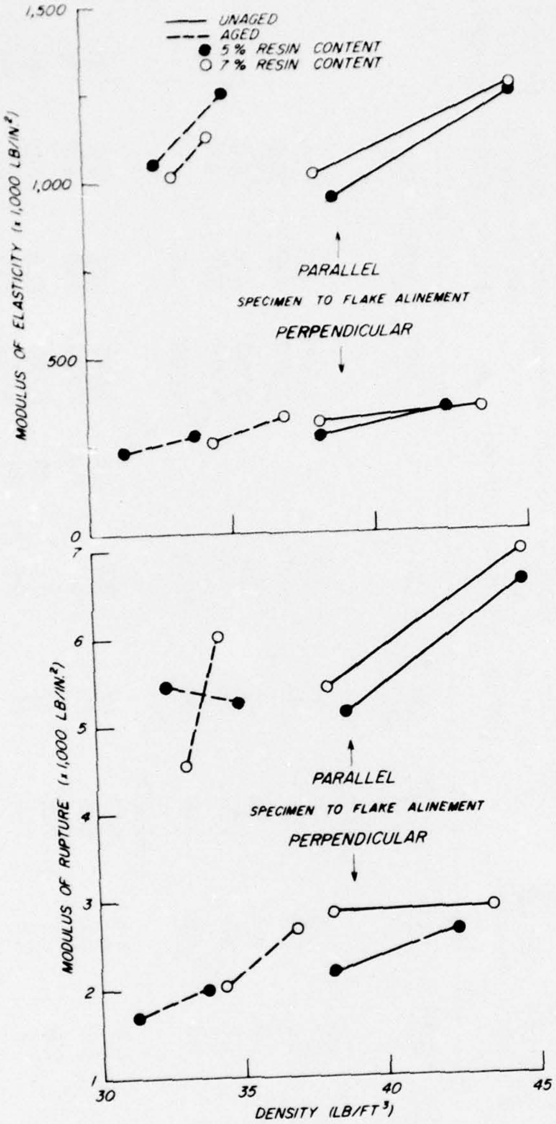

Figure 2. -- Relationship of MOE and MOR to resin content and density for Douglas-fir structural flakeboards with alined face flakes, both before and after accelerated aging. (From table 3.)

(M 144 019)

Table 3. — Properties of static bending specimens of Douglas-fir structural particleboards with alined face flakes

Target density	Resin content	Flake alinement[1]	Average moisture content	Density[2] Average	Density[2] Standard deviation	Density[2] Coefficient of variation	Modulus of elasticity Average	Modulus of elasticity Standard deviation	Modulus of elasticity Coefficient of variation	Modulus of elasticity Percent of unaged	Modulus of rupture Average	Modulus of rupture Standard deviation	Modulus of rupture Coefficient of variation	Modulus of rupture Percent of unaged
Lb/ft³	Pct		Pct	Lb/ft³	Lb/ft³	Pct	1,000 lb/in.²	1,000 lb/in.²	Pct		Lb/in.²	Lb/in.²	Pct	
							UNAGED[3]							
37	5	P	8.4	38.7	3.1	8.4	947	155	16.3	--	5,130	998	19.4	--
		X	9.0	38.1	2.5	5.9	274	20	7.2	--	2,190	137	6.3	
	7	P	8.5	38.1	1.9	4.3	1,016	95	9.4	--	5,420	482	8.9	--
		X	9.1	38.1	1.2	3.4	314	32	10.3	--	2,850	299	10.5	--
43	5	P	8.2	44.9	1.2	3.4	1,247	50	4.0	--	6,620	944	14.2	--
		X	8.9	42.4	1.9	4.6	359	33	9.2	--	2,640	696	26.3	--
	7	P	8.1	44.9	1.9	3.8	1,265	53	4.2	--	6,980	808	11.6	--
		X	8.7	43.7	0.6	1.8	346	23	6.6	--	2,900	477	16.4	--
							AGED[4]							
37	5	P	9.1	32.4	0.6	1.9	1,049	17	1.6	111	5,460	231	4.2	106
		X	9.1	31.2	--	.8	232	31	13.4	85	1,700	124	7.3	78
	7	P	8.9	33.1	1.2	3.2	1,014	56	5.5	100	4,550	291	6.4	84
		X	8.9	34.3	1.2	3.7	255	12	4.9	81	2,020	136	6.7	71
43	5	P	8.6	34.9	1.2	4.2	1,249	47	3.7	100	5,260	1,580	30.0	79
		X	8.7	33.7	1.2	3.0	280	20	7.0	78	2,000	210	10.5	76
	7	P	8.3	34.3	4.4	13.3	1,171	270	23.1	92	6,110	1,380	22.6	88
		X	8.3	36.8	0.6	1.2	331	42	12.7	96	2,690	212	7.9	93

[1]P is parallel to and X is perpendicular to specimen length.

[2]Based on dimension at test and ovendry weight.

[3]Average values based on 4 specimens conditioned to EMC at 73° F and 64 pct RH.

[4]Average values based on 2 specimens conditioned to EMC at 73° F and 64 pct RH. Bending properties calculated using dimensions before aging.

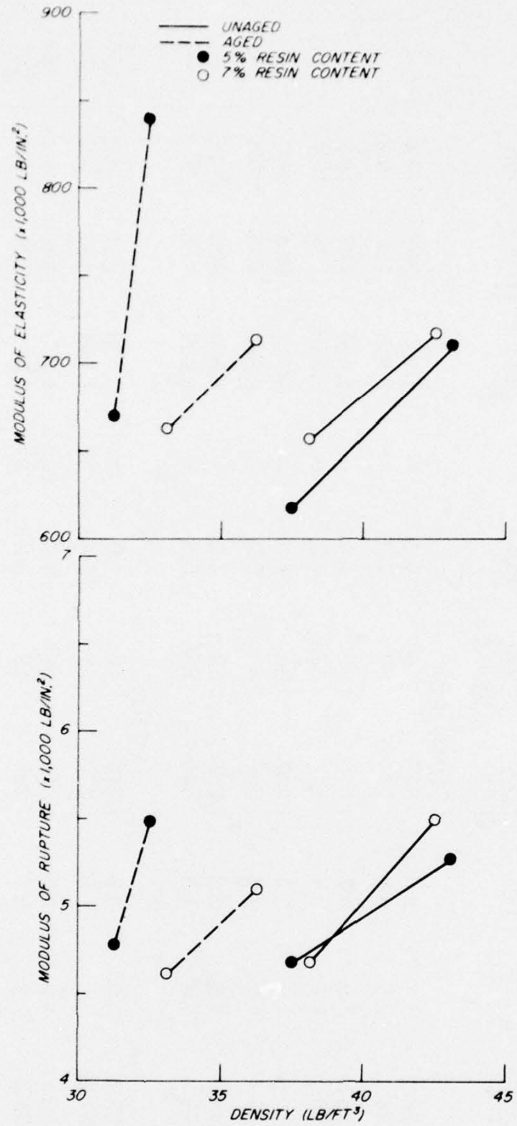

Figure 3. -- Relationship of MOE and MOR to resin content and density for lodgepole pine structural flakeboards with random face flakes, both before and after accelerated aging. (From table 4.)

(M 144 018)

Table 4. — Properties of static bending specimens of lodgepole pine structural particleboard with random face flakes

Target density	Resin content	Average moisture content	Density[1]			Modulus of elasticity				Modulus of rupture			
			Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation	Percent of unaged	Average	Standard deviation	Coefficient of variation	Percent of unaged
Lb/ft³	Pct	Pct	Lb/ft³	Lb/ft³	Pct	1,000 lb/in.²	1,000 lb/in.²	Pct		Lb/in²	Lb/in.²	Pct	
						UNAGED[2]							
37	5	9.1	37.4	1.9	5.4	618	47	7.5	--	4,680	603	12.9	--
	7	9.0	38.1	1.2	2.6	657	56	8.5	--	4,680	318	6.8	--
43	5	9.1	43.1	0.6	2.1	710	29	4.0	--	5,270	353	6.7	--
	7	9.1	42.4	0.6	1.9	717	27	3.8	--	5,500	392	7.1	--
						AGED[3]							
37	5	8.6	31.2	1.2	4.3	670	58	8.6	108	4,780	520	10.9	102
	7	8.6	33.1	0.6	1.6	663	52	7.9	101	4,620	507	11.0	99
43	5	8.9	32.4	1.2	3.3	839	43	5.1	118	5,480	485	8.8	104
	7	9.3	36.2	0.6	1.7	714	46	6.4	100	5,100	323	6.4	93

[1]Based on dimensions at test and ovendry weight.

[2]Average values based on 8 specimens conditioned to EMC at 73° F and 64 pct RH.

[3]Average values based on 4 specimens conditioned to EMC at 73° F and 64 pct RH. Bending properties calculated using dimensions before aging.

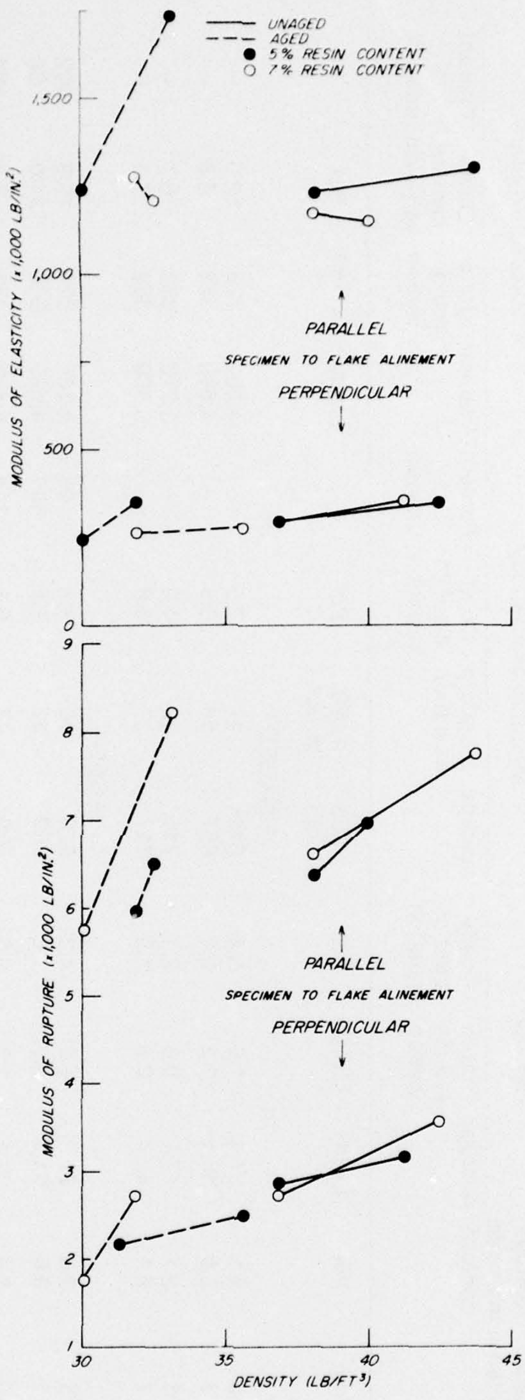

Figure 4. -- Relationship of MOE and MOR to resin content and density for lodgepole pine structural flakeboards with alined face flakes, both before and after accelerated aging. (From table 5.)

(M 144 016)

Table 5. — Properties of static bending specimens of lodgepole pine structural particleboards with alined face flakes

Target density	Resin content	Flake alinement to specimen length[1]	Average moisture content	Density[2]			Modulus of elasticity				Modulus of rupture			
				Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation	Percent of unaged	Average	Standard deviation	Coefficient of variation	Percent of unaged
Lb/ft³	Pct		Pct	Lb/ft³	Lb/ft³	Pct	1,000 lb/in.²	1,000 lb/in.²	Pct		Lb/in.²	Lb/in.²	Pct	
							UNAGED[3]							
37	5	P	8.5	38.1	0.6	2.0	1,230	50	4.0	--	6,620	978	14.8	--
		X	9.1	36.8	1.9	5.4	294	34	11.5	--	2,720	328	12.1	--
	7	P	9.0	38.1	1.2	3.6	1,171	66	5.6	--	6,380	469	7.4	--
		X	9.7	36.8	1.9	5.9	294	25	8.6	--	2,880	77	2.7	--
43	5	P	8.6	43.7	1.2	2.2	1,299	36	2.8	--	7,750	514	6.6	--
		X	9.1	42.4	1.2	3.7	348	21	6.2	--	3,560	378	10.6	--
	7	P	9.6	39.9	1.9	5.2	1,150	86	7.4	--	6,960	1,257	18.1	--
		X	9.6	41.2	0.6	1.4	350	10	3.0	--	3,150	400	12.7	--
							AGED[4]							
37	5	P	9.0	30.0	1.2	4.2	1,238	74	6.0	101	5,740	489	8.5	87
		X	9.0	30.0	--	0.8	248	9	3.5	84	1,750	41	2.3	64
	7	P	8.8	31.8	0.6	2.0	1,271	21	1.6	108	5,940	4	.1	93
		X	8.8	31.2	--	--	259	27	10.3	88	2,150	454	21.1	75
43	5	P	8.9	33.1	1.9	5.2	1,734	136	7.8	134	8,490	169	2.0	110
		X	8.9	31.8	1.9	5.9	356	52	14.6	102	2,710	334	12.3	76
	7	P	8.8	32.4	1.9	5.7	1,211	100	8.3	105	6,400	993	15.5	92
		X	9.1	35.6	0.6	1.4	280	31	11.1	80	2,500	76	3.1	79

[1]P is parallel to and X perpendicular to specimen length.
[2]Based on dimensions at test and ovendry weight.
[3]Average values based on 4 specimens conditioned to EMC at 73° F and 64 pct RH.
[4]Average values based on 2 specimens conditioned to EMC at 73° F and 64 pct RH. Bending properties calculated using dimensions before aging.

The alined flake panels of lodgepole pine (table 5, fig. 4) were 3.7 and 2.2 times as stiff and strong on the average in the alined direction as in the cross-alined direction. Good durability was again indicated by high strength and stiffness retention following the accelerated aging test (figs. 3 and 4).

The internal bond, direct nail withdrawal, nailhead pullthrough, and lateral nail resistance results for unaged Douglas-fir and lodgepole pine specimens (table 6), met or exceeded the Forest Service performance goals. Hardness values all exceeded 700 lb.

The effect of D 1037 aging on these properties can also be seen in table 6. Douglas-fir specimens with 5 pct resin content, and some with 7 pct resin content, did not meet the performance goal of 35 lb/in^2 retention of internal bond strength after aging. However, all nail withdrawal values equaled or exceeded the goals.

Strength and Elastic Properties--Group 2 Panels

The bending strength and elastic properties from the second group of panel types (defined in table 1) are presented in table 7 and figure 5. Data for each panel type are based on eight specimens taken from two panels. The use of 3-in.-long face flakes appeared to result in improved properties (fig. 5), while varying core flake thickness and moisture content produced mixed results. In a test for significant differences, an analysis of variance was performed using the MOE values from each board in table 7, and the hypothesis that they were different was rejected with 95 pct confidence.

Internal bond, direct nail withdrawal, lateral nail resistance, and hardness evaluations of the second specimen group are presented in table 8. Panels had stiffness and strength levels near or above the performance goals (tables 7 and 8). The internal bond aged values were also near or above the performance goal of 35 lb/in.^{2} retention after the ASTM D 1037 accelerated aging. This was a result of increasing the core flake thickness which resulted in more binder per unit flake area on the core flakes.

Based on processing ease, particularly resistance to "blown" boards, and the above results, the Douglas-fir panel with 10 pct face and core moisture, 0.02- by 1- by 2-in. disk face flakes, 0.05- by 2-in. ring flake core flakes, and a 1-min press closing time was selected for further structural evaluation in the Forest Service flakeboard program.

Because of the availability of larger volumes of material, Douglas-fir was selected for more thorough study, although lodgepole pine would also have been suitable. The uniform moisture content and 2-in. disk flakes were selected for ease in fabrication; the thicker (0.05-in.) core flakes were selected to improve internal bond; and the 1-min closing time was found to produce the density gradient desired in panels of this type.

Dimensional Stability

The dimensional stability data are summarized in tables 9 and 10 for the two groups of panels. In table 9, the effects of species, flake alinement, resin content, and panel density are shown.

Linear expansion (LE) not exceeding the target level of 0.25 pct in 30 or 90 pct RH was easily achieved by all random panels of both species. In the direction perpendicular to alinement, however, LE in all alined panels significantly exceeded the target level. Resin content did not affect LE, but lower density generally appeared to produce less LE. In the 24-h watersoak test, less LE occurred at the higher density level with Douglas-fir in both panel types, but not with lodgepole pine.

In the OD-VPS test, however, density had no effect on LE. Resin content had no effect in either the watersoak test or in the OD-VPS test. As with thickness swelling more LE was associated with lodgepole pine panels than with Douglas-fir panels.

Thickness swelling (TS) in 30 to 90 pct RH was in the range of 6.9 to 11.8 pct with most panels slightly exceeding the 8 pct target level. Generally, slight improvements in TS were obtained at the higher density and resin content levels. In the 24-h watersoak test, however, higher TS was associated with lower density panels of Douglas-fir and higher density panels of lodgepole pine, although there appeared to be a resin content-density interaction with lodgepole pine. In the OD-VPS test, higher panel density caused greater TS. Higher resin content reduced TS in the humidity, watersoak, and OD-VPS tests.

Generally, Douglas-fir boards were more stable than lodgepole pine boards, while random or alined flake construction had little effect on TS.

With the second group of panels (defined in table 1), only two trends were noted in the dimensional stability tests. These were a slight improvement in LE when flake length was increased to 3 in. and a slight increase in thickness swelling when the 0.05-in.-thick core flakes were used.

Table 6. Average values[1] for internal bond, direct nail withdrawal, nailhead pullthrough, lateral nail resistance, and hardness for structural flakeboard

Face flake orientation[2]	Target density	Resin content	Internal bond		Direct nail withdrawal		Nailhead pullthrough		Lateral nail resistance[3] unaged	Hardness, unaged
			Unaged	Aged	Unaged	Aged	Unaged	Aged		
	Lb/ft^3	Pct	$Lb/in.^2$	$Lb/in.^2$	Lb	Lb	Lb	Lb	Lb	Lb
				DOUGLAS - FIR						
R	37	5	107	19	48	35	394	284	305	780
		7	136	50	70	63	480	278	318	780
	43	5	117	15	57	102	468	308	330	1,100
		7	135	49	68	160	525	376	338	1,000
A	37	5	92	15	52	74	356	302	261	770
		7	134	30	38	77	373	294	295	850
	43	5	86	12	72	84	509	380	348	1,190
		7	116	15	73	98	471	394	354	1,070
R	40	5	114	18	100	32	522	364	313	--
				LODGEPOLE PINE						
R	37	5	138	43	70	66	500	380	328	730
		7	175	75	54	105	404	368	322	820
	43	5	152	38	84	162	600	432	365	1,040
		7	177	7	74	136	540	534	358	960
A	37	5	130	52	86	57	510	326	372	--
		7	151	94	70	68	492	279	331	720
	43	5	156	39	107	108	601	383	386	980
		7	148	115	78	101	598	384	350	--

[1]Based on 2 specimens.
[2]Random (R) or Alined (A).
[3]Procedure slightly modified from ASTM D 1037.

Table 7. — Properties[1] of static bending specimens from second group of panels

Board code[2]	Average moisture content	Density[3]			Modulus of elasticity			Modulus of rupture		
		Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation	Average	Standard deviation	Coefficient of variation
	Pct	Lb/ft^3	Lb/ft^3	Pct	1,000 $lb/in.^2$	1,000 $lb/in.^2$	Pct	$Lb/in.^2$	$Lb/in.^2$	Pct
					DOUGLAS-FIR					
[4]10 - 10 - .02 - 2	9.0	41.8	1.9	4.9	773	96	12.4	5,100	744	14.6
10 - 10 - .02 - 3	8.5	41.2	1.9	5.2	831	111	13.4	5,920	1,063	18.0
10 - 10 - .05 - 2	8.8	41.8	1.9	4.2	812	52	6.4	5,390	773	14.4
10 - 10 - .05 - 3	8.8	41.8	1.9	5.0	795	100	12.6	5,450	789	14.5
12 - 8 - .02 - 2	8.3	40.6	1.9	4.3	795	93	11.7	5,210	811	15.6
12 - 8 - .02 - 3	8.2	41.8	1.9	4.3	864	57	6.6	6,220	511	8.2
12 - 8 - .05 - 2	8.7	40.6	1.9	4.0	760	92	12.2	4,710	1,002	21.3
12 - 8 - .05 - 3	8.5	41.2	1.2	3.1	870	105	12.1	5,520	798	14.4
[5]12 - 8 - .05 - 2	8.6	39.9	1.2	3.1	733	64	8.7	4,460	506	11.3
					LODGEPOLE PINE					
8 - 8 - .05 - 2	8.2	43.1	0.6	0.7	690	80	11.6	4,840	603	12.5

[1]Each value is average of 8 tests, 4 from each of 2 panels.

[2]Code for flakeboard composition. Meaning of the four numbers, left to right: face flake moisture content (pct); core flake moisture content (pct); core flake thickness (in.); face flake length (in.).

[3]Based on dimensions at test and OD weight.

[4]This panel from first group of specimens (DR405).

[5]Formed mat held 18 h before pressing.

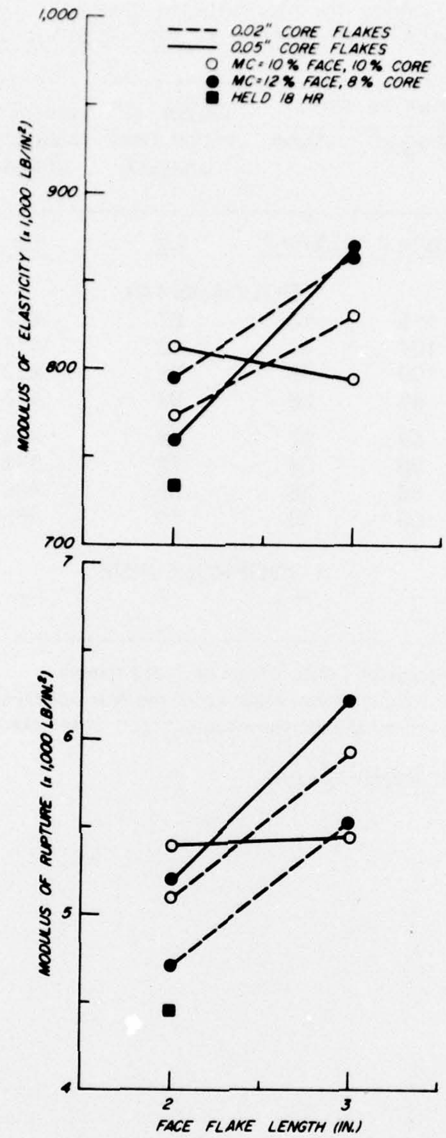

Figure 5. -- Relationship of MOE and MOR to flake length, flake thickness, and moisture content for Douglas-fir structural flakeboards with random face flakes.

(M 144 017)

Table 8. -- Average values[1] for internal bond, direct nail withdrawal, lateral nail resistance, and hardness for second group of panels

Board code[2]	Internal bond		Direct nail withdrawal, unaged	Lateral nail resistance, unaged	Hardness, unaged
	Unaged	Aged			
	Lb/in.^{2}	Lb/in.^{2}	Lb	Lb	Lb
			DOUGLAS-FIR		
10 - 10 - .02 - 3	116	30	87	422	1,069
10 - 10 - .05 - 2	101	40	93	414	916
10 - 10 - .05 - 3	100	36	99	420	1,010
10 - 8 - .02 - 2	85	26	93	417	906
12 - 8 - .02 - 3	89	32	88	434	924
12 - 8 - .05 - 2	90	34	72	398	815
12 - 8 - .05 - 3	85	28	85	400	845
[3]12 - 8 - .05 - 2	80	30	74	365	881
			LODGEPOLE PINE		
8 - 8 - .05 - 2	--	--	--	--	830

[1]Each value is an average of 4 tests, 2 from each of 2 panels.

[2]Code for flakeboard composition. Meaning of the four numbers, left to right: face flake moisture content (pct); core flake moisture content (pct); core flake thickness (in.) face flake length (in.).

[3]Formed mat held 18 h before pressing.

Table 9. — Values[1] of dimensional stability of structural flakeboards of Douglas-fir or lodgepole pine of random or alined face-flake construction and varying density and resin content

Face flake orientation[2]	Target density	Resin content	Flake alinement to specimen length[3]	50 - 90 percent relative humidity			30 - 90 percent relative humidity			24-hour water soak			Ovendry - vacuum - pressure - soak		
				Linear expansion	Thickness swelling	Water absorption	Linear expansion	Thickness swelling	Water absorption	Linear expansion	Thickness swelling	Water absorption	Linear expansion	Thickness swelling	Water absorption
	Lb/ft³	Pct		Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct
							DOUGLAS-FIR								
R	37	5	--	0.10	9.5	9.4	0.17	10.5	11.0	0.10	18.1	57.3	0.32	25.1	116.3
		7	--	.11	7.7	9.4	.19	8.5	11.0	.10	14.0	51.3	.30	19.7	116.6
	43	5	--	.10	8.0	8.4	.16	8.7	9.8	.03	7.8	18.1	.28	31.2	100.4
		7	--	.14	7.9	8.9	.20	8.8	10.3	.04	8.3	25.4	.30	25.0	99.2
A	37	5	P	.05	9.3	9.2	.10	10.2	10.8	.02	16.1	55.9	.17	24.5	120.6
			X	.21	--	--	.32	--	--	.21	--	--	.64	--	--
		7	P	.05	7.8	9.3	.11	8.5	10.9	.04	12.7	49.0	.21	21.2	112.0
			X	.22	--	--	.33	--	--	.20	--	--	.66	--	--
	43	5	P	.06	7.6	8.2	.11	8.5	9.7	.02	10.5	23.4	.18	30.9	109.7
			X	.28	--	--	.40	--	--	.13	--	--	.34	--	--
		7	P	.09	7.5	8.5	.15	8.3	9.8	.03	11.0	30.6	.21	25.2	98.2
			X	.35	--	--	.47	--	--	.14	--	--	.89	--	--
R	40	5	--	.09	9.6	9.0	.16	10.3	10.5	.10	17.3	46.1	.33	27.8	110.3
							LODGEPOLE PINE								
R	37	5	--	.15	10.2	10.0	.23	11.1	11.6	.09	22.6	61.4	.33	29.3	119.1
		7	--	.15	9.4	10.8	.24	10.1	12.2	.10	17.7	54.9	.34	25.2	108.9
	43	5	--	.15	8.9	9.1	.23	9.5	10.4	.13	23.9	52.9	.36	35.9	109.5
		7	--	.17	7.2	9.4	.25	8.9	10.7	.09	12.5	40.7	.35	27.9	95.2
A	37	5	P	.08	10.8	10.2	.14	11.8	11.8	.04	23.5	67.8	.24	29.1	122.8
			X	.30	--	--	.43	--	--	.35	--	--	.73	--	--
		7	P	.09	9.8	10.6	.15	10.5	12.2	.06	19.1	64.6	.24	25.8	115.5
			X	.27	--	--	.39	--	--	.32	--	--	.73	--	--
	43	5	P	.10	8.7	8.6	.17	9.4	9.9	.06	24.8	57.3	.24	35.7	113.2
			X	.35	--	--	.47	--	--	.36	--	--	.90	--	--
		7	P	.11	6.3	8.4	.17	6.9	9.8	.04	16.8	50.6	.23	26.4	103.6
			X	.34	--	--	.47	--	--	.30	--	--	.74	--	--

[1]Each value is average of 4 measurements except in linear expansion with alined flakeboards where 2 specimens were averaged for each value.
[2]Random (R) and Alined (A).
[3]P is parallel to and X perpendicular to specimen length.

Table 10. — Dimensional stability of structural flakeboards from second group of panels[1] defined in table 1

Board code[2]	50 - 90 percent relative humidity			30 - 90 percent relative humidity			Ovendry - vacuum - pressure - soak		
	Linear expansion	Thickness swelling	Water absorption	Linear expansion	Thickness swelling	Water absorption	Linear expansion	Thickness swelling	Water absorption
	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct
				DOUGLAS-FIR					
[3]10 - 10 - .02 - 2	0.10	9.6	9.0	0.17	10.3	10.5	0.33	27.8	110.3
10 - 10 - .02 - 3	.07	9.6	8.9	.12	10.7	10.6	.18	26.5	108.7
10 - 10 - .05 - 2	.10	10.5	9.1	.16	11.7	11.0	.23	32.8	119.6
10 - 10 - .05 - 3	.11	10.4	8.7	.16	11.6	10.7	.21	33.9	122.1
12 - 8 - .02 - 2	.07	8.4	8.2	.12	9.6	10.2	.22	27.3	119.6
12 - 8 - .02 - 3	.07	8.4	8.0	.12	9.4	9.9	.19	25.9	111.4
12 - 8 - .05 - 2	.07	9.3	8.6	.13	10.4	10.7	.22	30.6	122.3
12 - 8 - .05 - 3	.07	10.1	8.8	.13	11.3	10.9	.21	31.8	122.5
[4]12 - 8 - .05 - 2	.05	9.9	8.8	.10	11.2	10.9	.18	31.7	125.2
				LODGEPOLE PINE					
8 - 8 - .05 - 2	.16	8.3	8.6	.27	9.2	10.3	.40	31.2	112.5

[1]Each value is an average of 4 specimens, 2 from each of 2 panels.

[2]Code for flakeboard composition. Meaning of the four numbers, left to right: face flake moisture content (pct); core flake moisture content (pct); *core flake thickness (in.); face flake length (in.).*

[3]This panel from first group of specimens (DR405).

[4]Formed mat held 18 h before pressing.

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COM 2-4

U.S. Forest Products Laboratory.

High-performance structural flakeboards from Douglas-fir and lodgepole pine forest residues, by Terry J. Ramaker and William F. Lehmann. Madison, Wis., FPL 1976.

21 pp. (USDA Forest Serv. Res. Pap. FPL 286).

Evaluates the performance of flakeboards from forest residues in terms of proposed structural flakeboard target goals.

KEYWORDS: Species, flake alinement, density, bending strength, bending stiffness, resin quantity.

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Summary

Several variables were investigated in structural flakeboards using typical western forest residues. This research was part of the Forest Service Research Program effort to produce flakeboard to meet performance goals for structural building panels. Variables included the species of Douglas-fir and lodgepole pine, panel density, resin content, panel construction with random or alined face flakes, flake moisture content, length of face flakes, and thickness of core flakes.

Acceptable strength and stiffness properties were found to be attainable using random flake construction. Alined face construction will produce high strength and stiffness even more easily, except that linear instability perpendicular to face flake alinement can pose serious problems in service. (But linear instability could be reduced in face-alined board by cross-alining the core flakes.)

Random face flake constructions were found adequately stable in both panel directions. The Douglas-fir panels appeared to offer the most promise of the desired strength and stiffness levels at the density level of a structural panel. Thickness stability remained a problem with all variable levels except at an uneconomically high resin content level. The use of thicker core flakes to improve internal bond levels also somewhat aggravated the thickness swelling problem.

The final selection of a panel type for further evaluation in manufactured 4- by 8-ft panels was based on a compromise between minimal processing problems and optimum property levels. Thus, random flake panels will be produced in three-layer construction using 0.02- by 2-in. face flakes, 0.05- by 2-in. ring flake cores, bonded with 5 pct phenolic resin, and pressed to a density of approximately 40 lb/ft^3. Some difficulties may arise when using this board to achieve the previously mentioned performance goals in a conventional manufacturing process. Ways of improving board properties further, as shown in this and previous studies, would be: Increasing density; increasing flake length; increasing amounts of face flakes; and removing bark and decayed wood fractions.

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